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INFLUENCE OF HEAT TREATMENT ON ABRASIVE WEAR RESISTANCE OF SILUMIN MATRIX COMPOSITE CASTINGS

The authors attempted at examining the effect of heat treatment on abrasive wear resistance of metal composite castings. Metal matrix composites were made by infiltrating preforms created from unordered short fibers (graphite or silumin) with liquid aluminium alloy AlSi12(b). Thus prepared composites were subject to solution heat treatment at a temperature of 520°C for four hours, then aging at a temperature of 220°C for four hours. Abrasion resistance of the material was tested before and after thermal treatment.

Key words: metal composite castings; thermal treatment; tribology; aluminium alloy.

1. Introduction

Metal composites have been in use as engineering material widely for many years all over the world and in Poland as well. Their wide range of applications results from their good strength properties, low specific gravity, relative ease in forming the material and the possibility of making pieces of various sizes. The diversity of manufacturing methods and possible changes in material properties depending on the components used is undoubtedly their greatest advantage [1-4].

Metal composites, however, are continuously being improved by changes in the technological process. For instance, special alloy additives are used, reinforcements are subject to special preparation, (to facilitate bonds between components by changing the wetting angle) or by plastic or thermal treatment of ready products. These authors have been concerned with the technology of metal composite castings for years. One of the manufacturing methods we use is melt infiltration of the reinforcement structure (mostly ceramic) with liquid matrix metal applied under a pressure [5-10]. Thus made materials were thermally treated. The treatment consisted in solution heat treatment and aging, then the abrasive wear of samples was examined in order to determine how such treatment affects their tribological properties.

2. Tested material

The method used for making composite alloys consists in infiltrating a porous structure of the reinforcement phase with liquid alloy (composites with infiltrated reinforcement), in most cases squeeze infiltration is applied [3] – Fig. 1.
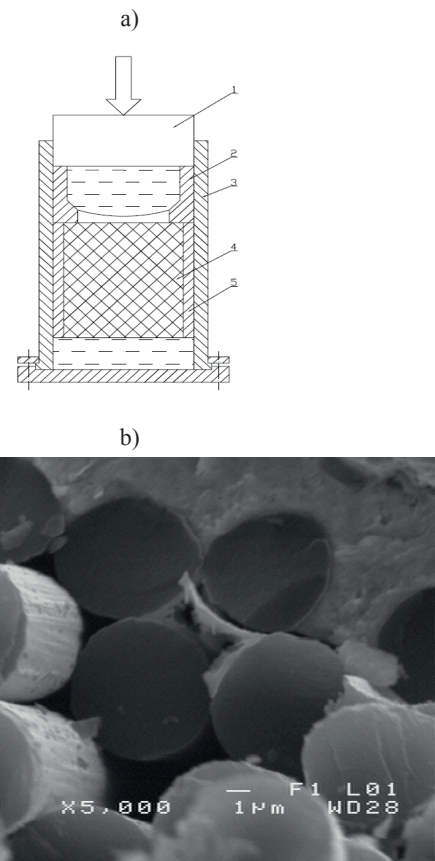
a)

b)

Fig. 1. Making composites by infiltrating a porous structure with liquid matrix metal, a) mould with a profile – preform prepared for infiltration [3]: 1 – stamp, 2 – piston, 3 – sleeve, 4 – ceramic profile, 5 – reinforcement nest; b) fracture of a composite with infiltrated reinforcement, (SEM)

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The matrix was an aluminium alloy (AlSi12(b)), while the reinforcement – preforms from unordered short fibers – in one case: graphite, in the other case: silumin.

The produced composites were processed thermally in a chamber furnace made by Nabertherm. The composites underwent solution heat treatment at a temperature of 520°C for four hours, then aging was applied at 220°C for four hours. The selection of temperature and time was based on the data presented by Pietrowski in [5-6]. Fig. 2 presents microstructures of the examined materials.
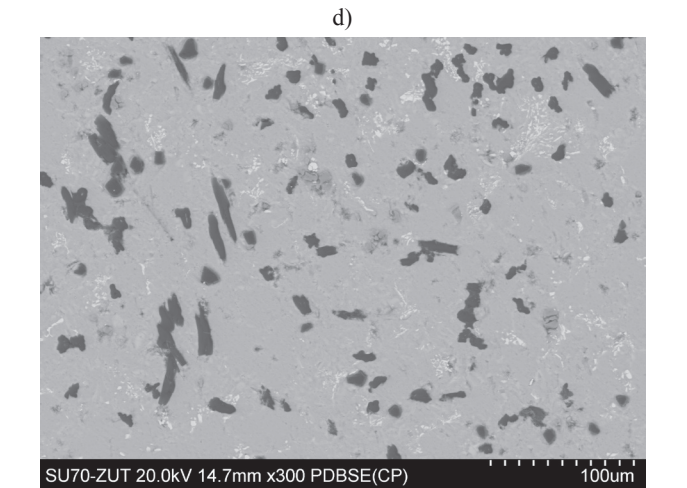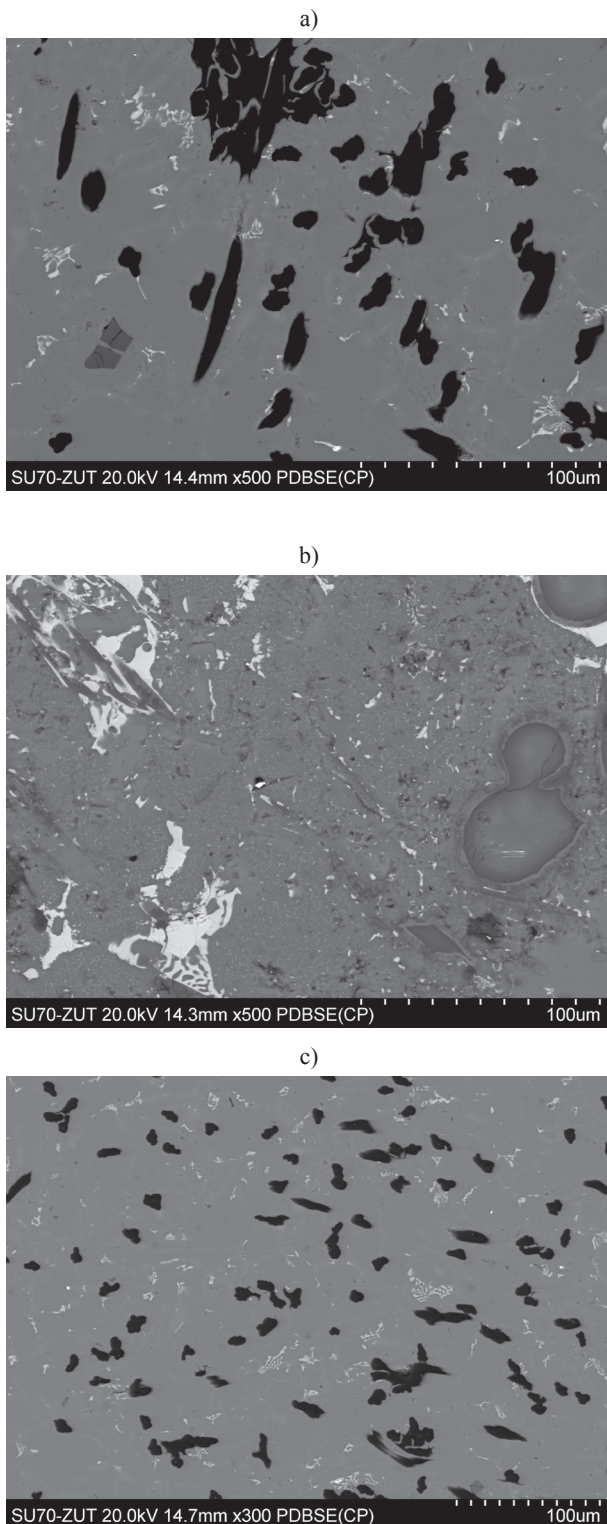
a)

b)

c)

d)

Fig. 2. Microstructures of the tested materials: a, b - AlSi12 composite (b)/graphite; c, d - AlSi12 composite(b)/silumin; (SEM). Materials: b, d – after aging at 220°C for four hours

3. Abrasive wear resistance tests by the ball-on-disk method

Abrasive wear resistance tests were done at the Institute of Materials Engineering, West Pomeranian University of Technology (ZUT) using the device TRN S/N 18−324, from CSM Instruments, combined with the TriboX v.2.96 system. The method was chosen because it is well documented in the professional literature and recognized as a recommended method for comparative tests of tribological properties of materials. The method, described in the US in the ASTM G 99−90 standard, at present has no equivalent in Polish or WEU standards.

Balls with a 6 mm diameter made of aluminium oxide were used as countersamples. The countersamples pressure was selected by a special program ModelX, a component of the above mentioned system. The selected load was 1 N. The friction distance of 200 m and linear speed of 3 cm/s were adopted. The tests were made using reciprocal motion. The tribotester recorded the friction coefficient and wear depth in time (and as a function of friction distance). Tests were made at a temperature of 23°C and relative air humidity 45-55 %. After testing, the samples were measured for wear length, using an optical microscope (Nikon MM−40) with a special measurement bench connected to a computerized counter (Nikon Digital Counter SC−212). Afterwards, to determine the area of wear trace its profile was measured using a Veeco-made profilometer Dektak 6M with Dektak32 software. The measurements were performed for the following parameters: scanning length: 1500 - 2000 μm, radius of scanning stylus: 5 μm, measurement range: 265 μm, scanning time: 60 s, stylus pressure: 3 mg. Lines of profile acquisition were placed at a right angle to the wear traces, attaining the cross-section profile of the wear trace. For each wear trace five profiles were collected. An example profile measured using the profilometer is shown in Fig. 3.
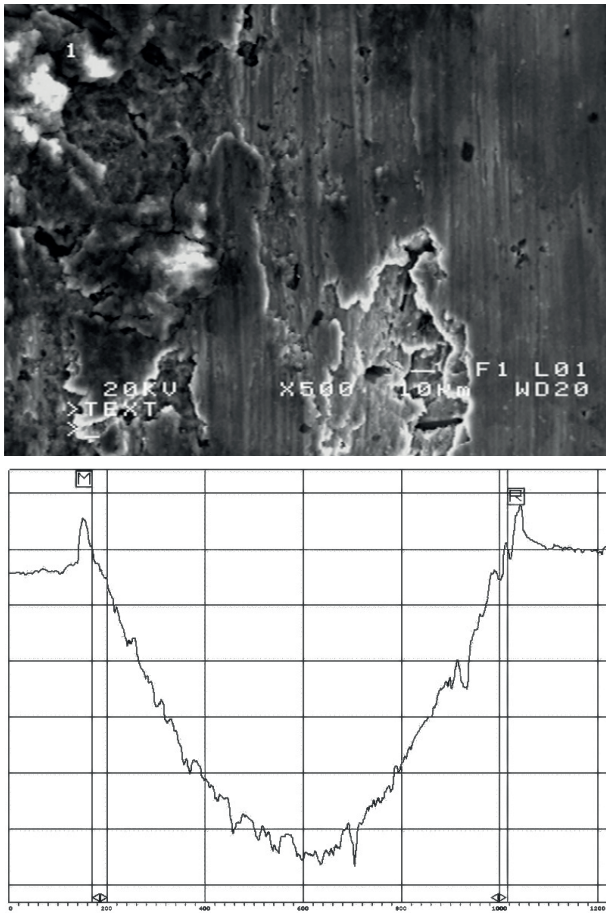
Fig. 3. An example image (SEM) and profile (composite AlSi12(b)/graphite) collected by the profilometer

TABLE 1
Results of the ball-on-disk tests, no heat treatment

Sample	Wear rate **K** $[\frac{\mu m^3}{N \cdot m}]$	Standard deviation $[\frac{\mu m^3}{N \cdot m}]$
AlSi12(b)/graphite	**881163**	71428
AlSi12(b)/silumin	**1466898**	335105

TABLE 2
Results of the ball-on-disk tests, after heat treatment

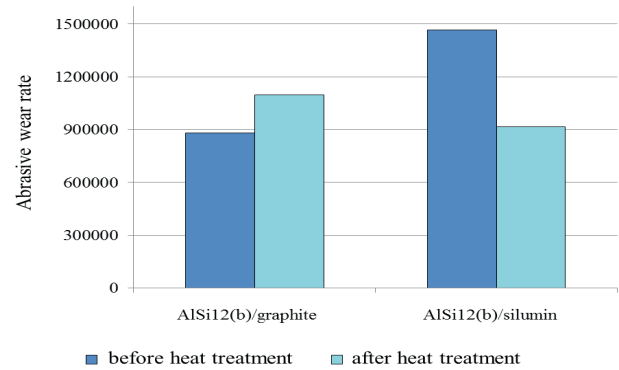| Sample	Wear rate **K** $[\frac{\mu m^3}{N \cdot m}]$	Standard deviation $[\frac{\mu m^3}{N \cdot m}]$
AlSi12(b)/graphite	**1097840**	71790
AlSi12(b)/silumin	**915000**	158826

Fig. 4. Abrasive wear rate for the tested materials before and after heat treatment (solution heat treatment at 520°C/4h and aging 220°C/4h)

The profilometer measurement result was the surface area (computed as an area between the line zero and the profile) corresponding to the area of cross-section removed due to abrasion of the surface layer. The next step was to calculate the volume of sample material worn during the tests, where the wear distance and mean area of wear trace were known. The wear rate, determined from the formula (1) is given in Tables 1 and 2 and Fig. 4. Three samples of each material were tested, and the results were averaged.

$$K = \frac{V}{F \cdot S} \qquad (1)$$

where

K – wear rate $[\frac{\mu m^3}{N \cdot m}]$,
F – pressure $[N]$,
S – friction distance $[m]$,
V – total volume loss $[\mu m^3]$,

$$V = V_{pr} + V_{kul} \qquad (2)$$

where
V_{pr} – volume loss in a sample $[\mu m^3]$,
V_{kul} – volume loss in a countersample $[\mu m^3]$.

4. Summary and conclusions

It follows from Tables 1 and 2 and Figure 4 that the composite AlSi12(b)/silumin before thermal treatment has the lowest resistance to abrasive wear. In the case of this composite alloy - AlSi12(b)/silumin - solution heat treatment and aging resulted in better resistance to abrasive wear (Fig. 4). It is known that phase precipitation from supersaturated solid solution in silumin is attained by annealing at a temperature at which the equilibrium structure is 'pure' solid solution, then cooling the material to a temperature at which the solid solution is metastable, and the mixture of two phases is the stable structure [5, 11]. The condition that has to be satisfied for aging to be applied is changing solubility of the component along with temperature decrease, and the process is referred to as precipitation strengthening [5-6]. In the process of silumin annealing for solution heat treatment there occurs coalescence and coagulation of silicon. The former consists in joining of those silicon crystals that are close to each other and have a shape of long plates. In the process silicon crystals maintain their plate-shaped morphology. It is supposed [5] that in the process of silumin annealing for solution heat treatment interphase β/α migration occurs and the concentration of silicon increases in the solid solution of aluminium (α) to the value

close to the equilibrium at the annealing temperature. In this connection, silicon diffusion occurs from two neighbouring crystals to the solid solution α. Silicon diffusion across the interphase boundary is facilitated due to boundary incoherence. The diffusion takes place along and across the boundary as a result of its 'porosity' [5]. Due to incoherent boundaries silicon crystals are able to migrate at a rate determined only by factors independent of the boundary structure, i.e. concentration difference of Si solved in Al at the contact with the boundary of Si/Al (α/β) and unchanged silumin, local curvature of the Si/Al (α/β) boundary and Si-in-Al diffusion coefficient. The concentration of an element solved in a matrix in an equilibrium with crystals of the second phase depends on a local curvature of interphase boundary due to the Gibbs-Thomson effect [5]. This also causes the coagulation of silicon crystals, consisting in diffusion-induced increase of larger particles and a simultaneous solution treatment of smaller particles in the silumin matrix, while the volumetric fraction of the second phase remains constant. Some phase β crystals, particularly those of large size, in the annealing process do not coagulate before solution heat treatment, only their corners and edges get rounded (Fig. 5)
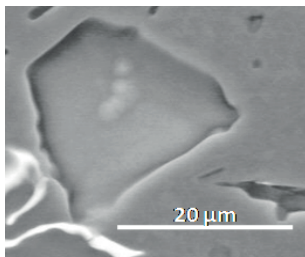

Fig. 5. Visible rounded corners of a phase β crystal after solution heat treatment and aging of silumin matrix (SEM)

Silumin improves its mechanical properties, including its resistance to abrasive wear, through coalescence and coagulation of silicon, and it is supposed that the same takes place in composites with silumin matrix, as shown in Fig. 4. The confirmation of this phenomenon can be found in Wierzbinski's study [7]. However, description of the problem requires additional research into modified silumins, the results of which will be presented in our future studies.

Abrasive wear of AlSi12(b)/graphite is the lowest (see Table 1, wear rate). This is presumably connected with the presence of graphite in the composite as the reinforcement phase. Lubricating properties of this material are commonly known [8]. Unfortunately, solution heat treatment and aging negatively affected tribological properties of the casting. Microscopic observations and X-ray microanalysis show that a hard brittle layer is formed at the boundary of the components, seen in Figures 2d and 6. SEM and X-ray microanalytic images show that the layer is Si-rich. This implies that silicon content in the matrix gets decreased and that silicon crystallizes on graphite reinforcement fibres. Microhardness tests confirm this, as shown in Fig. 7 depicting averaged values of microhardness of the tested composite matrix. The test was performed by the Vickers method to the Polish standard PN 79/H04361. The performed tests of the metal composite matrix, consisted in measuring the matrix area outside reinforcement fibres, before

and after heat treatment. As that layer is situated on the surface of graphite fibres, it makes up a specific insulation, which most probably reduces its effect as a lubricating agent.

This hypothesis is partly confirmed in works [9-11], but it requires further examination, also to be presented in future publications of the authors.
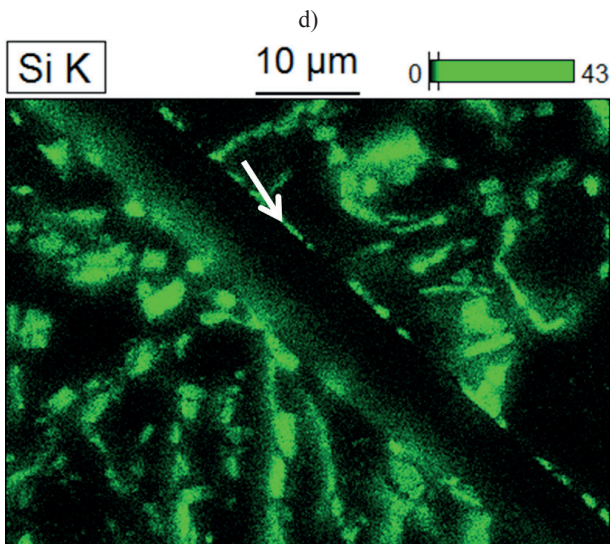
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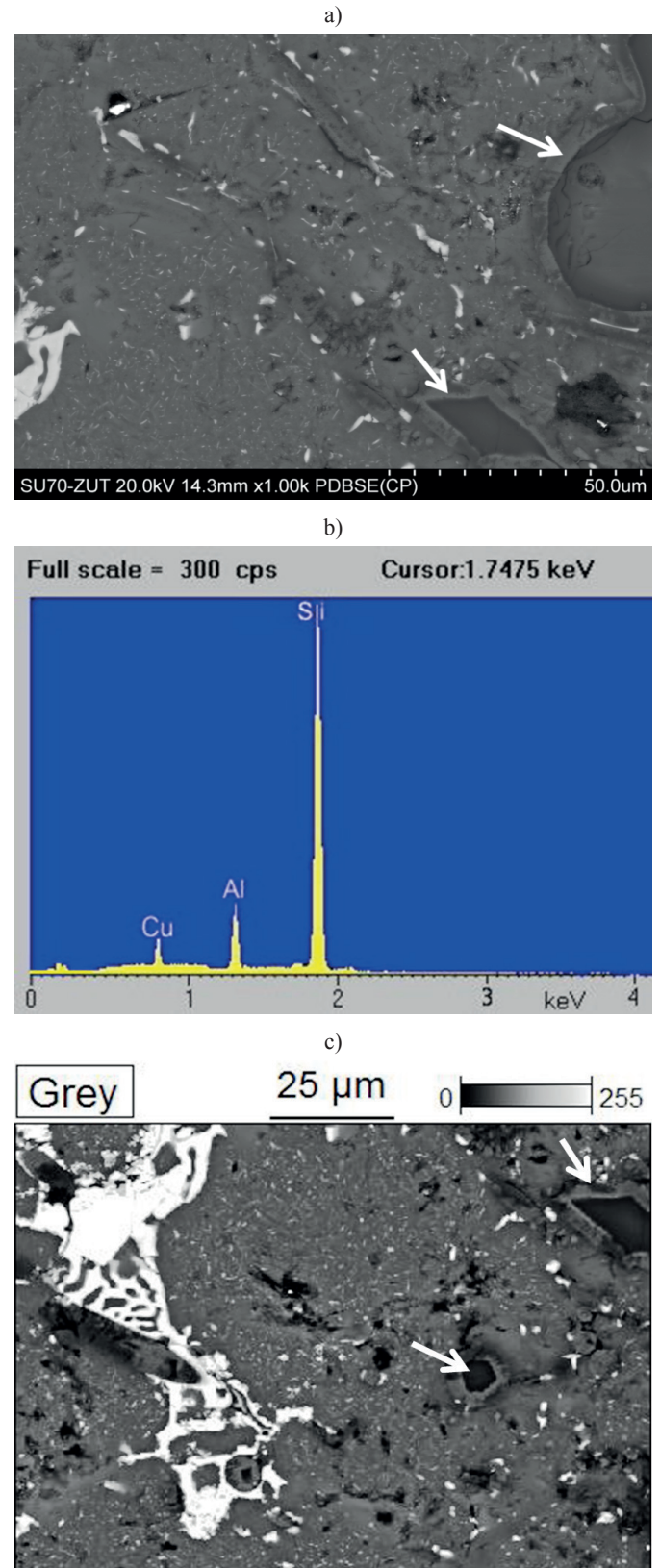
Fig. 6. Microstructures of a composite casting AlSi12(b)/graphite after heat treatment -a, c, d (SEM) with X-ray microanalysis - b. Chemical composition Wt%: Si 97,71%, Al 1.98%, Cu 0.2% , Fe 0.11%) at locations indicated by arrows
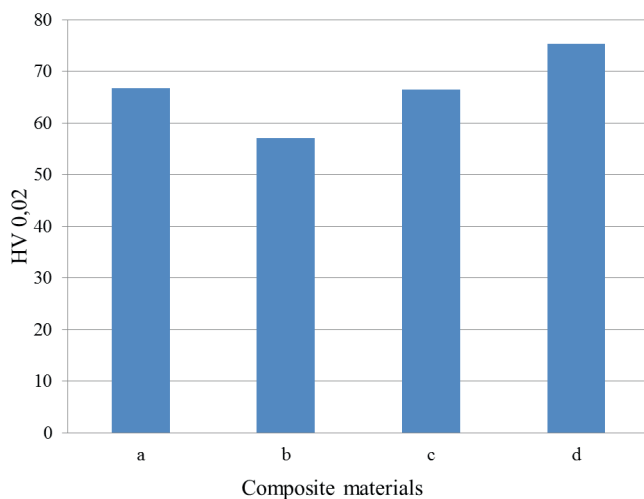

Fig. 7. Microhardness of the composite matrix a, b - AlSi12(b)/graphite; c, d - AlSi12(b)/silumin. Materials: b, d – after aging for 4 hours at 220°C

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